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The Research of the Genetic Algorithm Combined with Chromosome Fitness to Optimize the Flatness Error Evaluation

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Abstract. This paper suggests an improved genetic algorithm to seek the minimum range value in the ideal-plane flatness measurement. This algorithm increases measurement accuracy by using dynamic cross factor, mutation factor and a new concept called chromosome fitness. It was proved in simulation experiments that its accuracy is better than other flatness error evaluating algorithms like the minimal territory evaluating algorithm and the computational geometry algorithm etc. So it can be used for measuring industrial production components error and verifying assumed models in reverse engineering etc.

Introduction

In industrial production, the parts may have the position and shape errors. The errors not only affect the interchangeability of parts as well as the quality of the products [1]. Flatness is one of the main items of tolerances on shape, so that the correct way to detect and assess the shape error is of great significance for ensuring the quality of the parts and machinery products [2].

Nowadays, multidisciplinary partnerships is a significant feature of technology development, the flourishing genetic algorithm reflects this characteristic of scientific development [3]. Compared to traditional optimized algorithms, the genetic algorithm is better in lots of aspects, such as subject range, essentially parallel, global search ability and robustness [4].

Flatness measurement means the mutation between the measured actual plane and its ideal plane. Range value means the difference between the minimum and maximum distance from all measured points to the ideal plain. Measured data about the flatness range plays an important role in industrial design, reverse engineering, and demonstration test [5]. There are two main kinds of methods for flatness error evaluation, the approximate evaluation method and the minimal territory evaluating algorithm [6], the approximate evaluation method contain the least squares method, the diagonal method and the three far point method [7] [8]; the error calculated by the minimal territory evaluating algorithm is minimal and unique which is good for ensuring the quality of products [9]; Recently, a variety of algorithms about the minimal territory evaluation on the flatness error have been proposed, such as the pole calculation method, transform calculation method, transform mapping method, rotation transformation method [10]. They can get ideal results which meet the national standard [11]. However, these algorithms are all related to nonlinear problems so that they are difficult to code on computers and they require a lot of time to get the answer, the speed of convergence is slow so that it is difficult to meet the practical needs [1].

The genetic algorithm is a computational model of a simulation of natural selection in Darwin's theory of evolution and a natural evolution of the process for searching the optimal solution. This algorithm was first proposed in 1975 by professor J.Holland who published the famous work *Adaptation in Natural and Artificial Systems* in the University of Michigan, USA [13], so that the name of the genetic algorithm was gradually known. In 1989, Goldberg published the monograph *Genetic Algorithms in Search, Optimization and Machine Learning* [14], which made a systematic summary of the main research achievements of the genetic algorithm completely, discussed the basic principles and applications of the genetic algorithm, laid the modern genetic algorithm's scientific basis.

Compared to other algorithms, encoding the measured value and then solving the problems about the errors has more improvement on efficiency. Although the genetic algorithm has lots benefits such as easy to implement, simple on concept, it also has some defects like large time costs, but the basic genetic algorithm still has a lot of problems such as a long calculation time, precocity(local optimal solution), or slow speed of convergence [15]. Therefore, in order to solve these problems, this genetic algorithm is proposed.

To reduce the blindness of genetic algorithm, this paper proposed new ideas in fitness function and genetic operations: the concept of chromosome fitness is suggested on the basis of individual fitness, and the genetic operations are based on these two kinds of fitness function. Calculating by this new genetic algorithm is good for individuals toward better directions. The probability of involution is greatly decreased by leaving better chromosomes or some chromosomes which are not easy to cross or mutation, so that the better individual will appear constantly, the average value of individuals will drop stably.

In addition, as a calculation model of a simulation of the process of biological evolution of the genetic mechanism, the characteristics of the genetic algorithm have a lot of aspects in common with the process of natural evolution; the possibility of this algorithm to be applied in biology, yet to be further explored by biological researchers.

The Mathematical Model of the Flatness Shape Error

According to the provisions of relevant standards, the flatness error evaluation must meet the minimal territory conditions. Therefore the flatness error actually can be expressed into the minimum value of the difference between the maximum value and the minimum value of all the distances between measuring points and ideal plane.

Let the ideal plane equation:

$$\mathrm{a}X + bY + cZ = 0$$

The ideal plane's normal vector: $\vec{n} = (a, b, c)$

Then the flatness error $d_{\min}$ can be expressed as:

$$d_{\min} = \min\{\max\{\frac{aX_i + bY_i + cZ_i}{\sqrt{a^2 + b^2 + c^2}}\} - \min\{\frac{aX_i + bY_i + cZ_i}{\sqrt{a^2 + b^2 + c^2}}\}\}.$$

The aim of this algorithm is to find out the idea plane with minimum flatness error according to the existing measuring data.

Calculate the Flatness Shape Error with Genetic Algorithm

Coding Scheme. This algorithm uses multidimensional normalized real number coding.

Normalized real number coding means code in the interval [0, 1], the decimal places are their genes which have 10 possible values.

Each individual is made of three chromosomes, and each chromosome includes a gene sequence. For the flatness error of ideal plains can be described by a three-dimensional normal vector, by dividing each dimension of the normal vector $\vec{n} = (a, b, c)$ with $\sqrt{a^2 + b^2 + c^2}$, each dimension of normal vector can be transformed into the interval [0, 1], and each transformed dimension can be regarded as chromosome.

Fitness Function Design. The fitness function of traditional genetic algorithm is only about the fitness of individuals. It cannot lead the mutation of individuals into a right direction, which may cause blind uncertain mutation and cross, and usually limit the solution set into a range, so that the efficiency and quality of genetic algorithm are greatly reduced.

According to these characteristics of traditional algorithm for calculating flatness error, this algorithm proposed chromosome fitness except for the individual fitness. The chromosome fitness is based on the individual fitness; it shows the influence of chromosome to individual. Operating chromosome by chromosome fitness helps to find out a quicker and more accurate way to find the best solution.

In this kind of genetic algorithm, chromosome fitness function becomes a constraint and a parameter for cross and mutation. Now let us talk about the feasibility of this algorithm.

First, according to the definition of the flatness error:

$$d_{\min} = \min\{\max\{\frac{aX_i + bY_i + cZ_i}{\sqrt{a^2+b^2+c^2}}\} - \min\{\frac{aX_i + bY_i + cZ_i}{\sqrt{a^2+b^2+c^2}}\}\} \quad (4.1)$$

Suppose there is a point $(X_{\max}, Y_{\max}, Z_{\max})$, let $\frac{aX_i + bY_i + cZ_i}{\sqrt{a^2+b^2+c^2}}$ to get to the maximum value.

Suppose there is another point $(X_{\min}, Y_{\min}, Z_{\min})$, let $\frac{aX_i + bY_i + cZ_i}{\sqrt{a^2+b^2+c^2}}$ to get to the minimum value.

So (4.1) the formula can be rewritten as:

$$d_{\min} = \frac{aX_{\max} + bY_{\max} + cZ_{\max}}{\sqrt{a^2+b^2+c^2}} - \frac{aX_{\min} + bY_{\min} + cZ_{\min}}{\sqrt{a^2+b^2+c^2}}$$

After simplify

$$d_{\min} = \frac{aX_{\max} - aX_{\min} + bY_{\max} - bY_{\min} + cZ_{\max} - cZ_{\min}}{\sqrt{a^2+b^2+c^2}}$$

Therefore define

$$f(a) = \frac{d_{\min}}{(aX_{\max} - aX_{\min})}, f(b) = \frac{d_{\min}}{(bX_{\max} - bX_{\min})}, f(c) = \frac{d_{\min}}{(cX_{\max} - cX_{\min})}$$

They can describe the impact of A, B, C three chromosomes to the value of $d_{\min}$, and then choose the chromosome which may impact $d_{\min}$ most to mutate.

During mutation, the algorithm requires the absolute value of the new chromosome less than that of the original chromosomes. This makes the mutation of the individuals is to the direction of the optimal solution.

Therefore, the definition of the individual fitness is below:

Suppose $d_{\min} = \min\{\max\{\frac{aX_i + bY_i + cZ_i}{\sqrt{a^2+b^2+c^2}}\} - \min\{\frac{aX_i + bY_i + cZ_i}{\sqrt{a^2+b^2+c^2}}\}\}$, so that define the individual fitness $\mathrm{f} = \frac{1}{d_{\min}}$

Define $l_{\max} = \max\{\frac{aX_i + bY_i + cZ_i}{\sqrt{a^2+b^2+c^2}}\}$, and suppose when $l_{\max}$ gets the maximum value, i=max.

Define $l_{\min} = \min\{\frac{aX_i + bY_i + cZ_i}{\sqrt{a^2+b^2+c^2}}\}$, and suppose when $l_{\min}$ gets the minimum value, i=min.

Define the chromosome fitness a, b, c:

$$f(a) = \frac{d_{\min}}{(aX_{\max} - aX_{\min})}, f(b) = \frac{d_{\min}}{(bX_{\max} - bX_{\min})}, f(c) = \frac{d_{\min}}{(cX_{\max} - cX_{\min})}$$

In addition, take attention to the situation when a=b=c=0, none of a, b and c can be 0 during cross and mutation.

The Optimized Design of Genetic Operations

The Initiation of Population. Take some random real numbers between 0 and 1 produced by random function to be the chromosomes of individuals.

Selection. Remain 40 percent of original individuals which have larger fitness function and then weed out half of the other 60 percent of individuals randomly and the positions of the disappeared individuals are taken by the first 40 percent individuals randomly.

Cross. Define the cross factor

$$p = \frac{f_i}{f_{\max}}$$

f_i means the individual fitness, $f_{\max}$ is the maximum fitness in the population. Accept for the best individual, other individuals will combine with other individuals randomly, when the two of the cross factors are larger than the presupposed cross factor; the two chromosomes which have smaller chromosome fitness will be in the cross.

Mutation. The mutation factor of individuals is the square of the cross factor of individuals.

When the mutation factor of one individual is larger than the presupposed mutation factor, it will mutate. The mutated chromosome is the chromosome which has minimum chromosome fitness. Suppose the mutated chromosome is a, the mutation function is $a = a + (f(a))^{-2} \bullet r$. R is a random variable with the range of -1 and 1. And the mutation requires that the absolute value of the produced chromosome is smaller than that of the original one.

The Judgment During the Iteration. For many 0s will be appeared in the coding real numbers during the cross and mutation, this algorithm contain the judgment of the fitness functions of new individuals, to make sure that all chromosomes are in the range of [0, 1] multiplied by 10^k.

Algorithm Theoretical Analysis

Time Complexity. In each generation, each individual is operated. Suppose T is the number of generations, MMAX is the number of individuals in one generation, then the time complexity if O(T*MMAX).

Space Complexity. In each generation, the new individuals and original individuals are recorded, each individual has three chromosomes. Therefore, suppose MMAX is the number of individuals in one generation, the space complexity is O(2*MMAX*3).

The Simulation Example

In this paper, large sum of simulation calculations of flatness error evaluation by this algorithm are taken. Table 1 shows one of the examples. The experimental environment is Windows XP, and the algorithm is written by C language. The hardware environment is RAM of 1GB, and the CPU clock speed is 2GHz.

Table 1:The raw data of flatness shape error Unit:[mm]

point	*x*	*y*	*z*	*Point*	*x*	*y*	*Z*
1	0.2	0.2	-0.064500	14	0.6	0.8	0.035150
2	0.2	0.4	-0.064380	15	0.6	1.0	-0.019970
3	0.2	0.6	0.008761	16	0.8	0.2	0.015400
4	0.2	0.8	-0.011170	17	0.8	0.4	-0.013240
5	0.2	1.0	-0.062370	18	0.8	0.6	-0.022250
6	0.4	0.2	-0.038290	19	0.8	0.8	0.077100
7	0.4	0.4	0.065500	20	0.8	1.0	-0.000359
8	0.4	0.6	0.063570	21	1.0	0.2	0.057730
9	0.4	0.8	0.028490	22	1.0	0.4	-0.056200
10	0.4	1.0	-0.006113	23	1.0	0.6	0.092060
11	0.6	0.2	-0.095250	24	1.0	0.8	0.065360
12	0.6	0.4	-0.011540	25	1.0	1.0	-0.021210
13	0.6	0.6	-0.024060				

When use the algorithm described in this paper, let the number of individuals in population N=1000, the cross factor and mutation factor be like the description above, the range of coding is [0,1], the numbers of generations are 300.

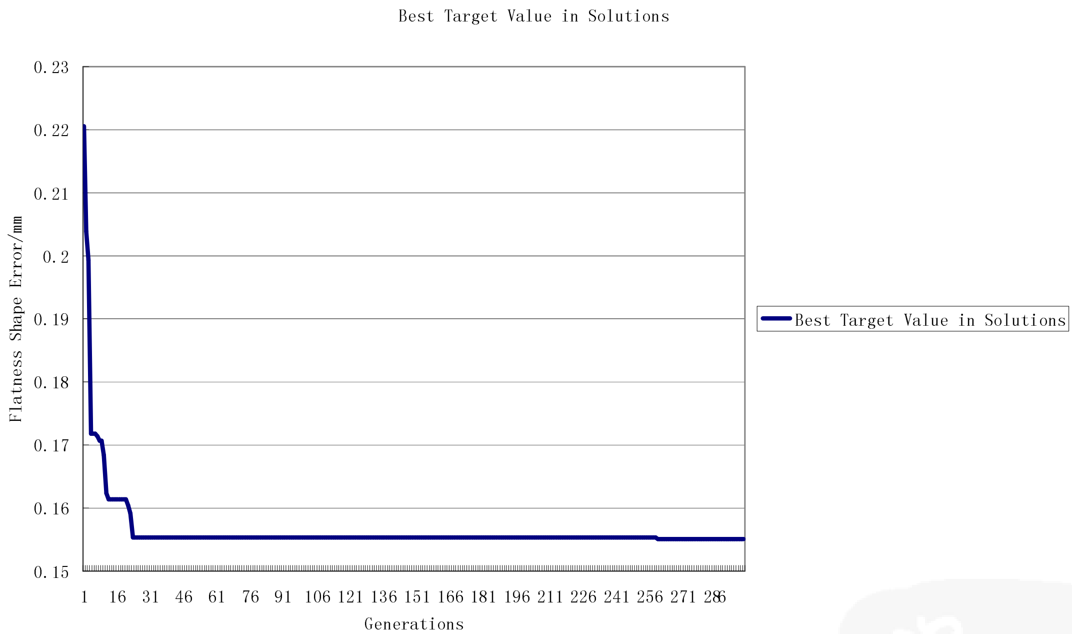

Fig.1.The best target value in solutions

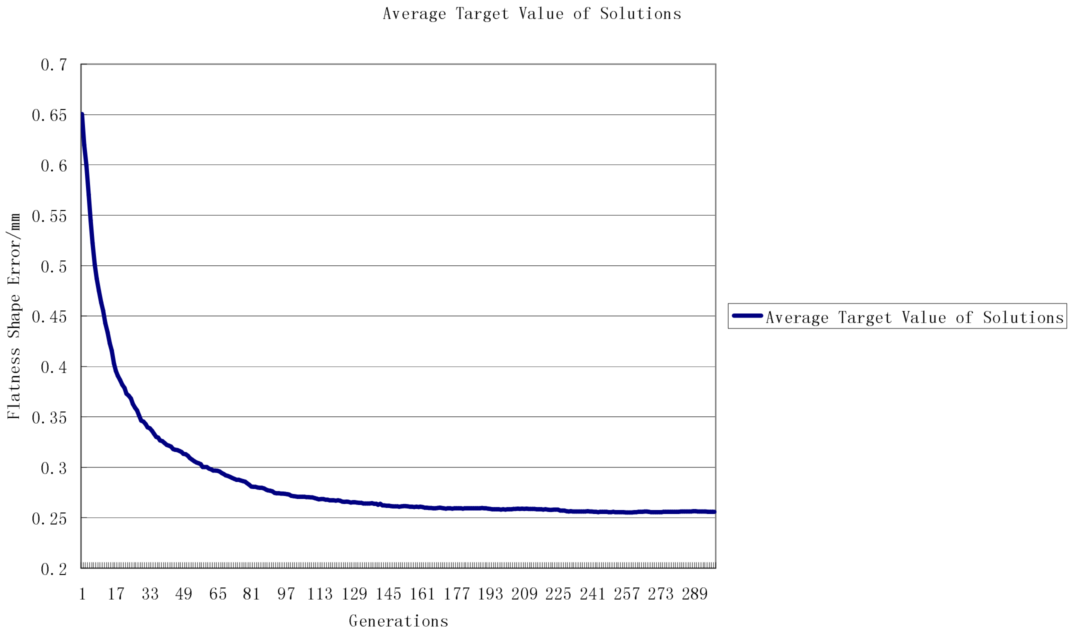

Fig.2.The average target value of solutions

Fig.1 shows that this algorithm may find the approximate best solution 0.1577mm around the 30th generation, and find out the better solution 0.1550mm in later generations, so as you can see, it doesn't sink into the local optimal solution. Fig.2 shows that this genetic algorithm is more stable than traditional genetic algorithm. The line which describes the average value of solutions of the tradition genetic algorithm has a lot of polylines because of the random cross and mutation, however, the line of this genetic algorithm is smoother because different parameters are chosen according to the characteristics of each chromosome and each individual.

This algorithm can get the optimal plain in which a= -0.0096657598037096, b= -0.0199800699492598, c= 0.3706668548669713, the flatness error evaluation result f= 0.1550404112603684. To compare with other algorithms, Table 2 gives the solution calculated by the minimal territory evaluating algorithm, the computational geometry algorithm, and the genetic algorithm used in the citation. This optimized algorithm is better than other algorithms obviously.

Table 2:The comparison of several different methods

Method	Flatness shape error[mm]
Minimal Territory Evaluating Algorithm [16]	0.173
Computational Geometry Algorithm [16]	0.162
Genetic Algorithm [2]	0.1566
Optimizational Genetic Algorithm	0.1550

Conclusions

When find out the ideal plain to calculate the flatness, if there are large amount of data, and a reasonable model cannot be sure in advance, a global search can be used by the algorithm in this paper. The example shows this algorithm has good convergence and accuracy. It is considered to combine this algorithm with parallel algorithm to improve the efficiency in future studies.

References

[1] Xueni Wang, Shi Zhan, *The Research of the Quick and Accurate Algorithm of Flatness Error Evaluation* [J], Instrument Technique, 2009 10$^{th.}$, In Chinese.

[2] Nengyun Dai, *The Study of the Methods of Evaluation of Geometrical Shape Error*, Zhongnan University (2010), In Chinese.

[3] Yinnian Wang, *The Research and Application of Genetic Algorithm – the Annealing Genetic Algorithm Based on the 3PM Cross Factor*, Jiangnan University (2009), In Chinese.

[4] Xiaobing Zhao, *The Research of Single Target and Multiple Target of Genetic Algorithm*[D], Tianjin Ligong University (2011), In Chinese.
[5] Sheping Tian, Hongyu Wei, Zhiwu Wang, *The Assessment of Flatness Error Evaluation by Genetic Algorithm* [J], Measuring Technique, 2007, (1), p.66-69, In Chinese.
[6] Wen Fang, *The Research of the Visualization Assessment System of the Flatness Error*[J], Manufacturing Automation, 2011-12(under), p.33-35, In Chinese.
[7] Ping Liao, *The Research of Shape Error Calculation Based On the Genetic Algorithm* [D], Zhongnan University (2002), In Chinese.
[8] Shili Wang, *Intelligent Evaluation of the Flatness of Large Size*, Huanan Ligong University (2010), In Chinese.
[9] Yongli Gan, Yun Song, Yabin Fang, *Shape and Error Location Detection* [M], Beijing, Defense Industry Publishing House, In Chinese.
[10] Kai Wang, *Shape and Location Tolerance Standard Application Guide*[M], Beijing : China Standard Publishing House. 1993, p.314-359, In Chinese.
[11] Jun Luo, Qiang Wang, Li Fu, *The Application of Optimized Bee Colony Algorithm in Flatness Error Evaluation*[J], Optics and Precision Engineering. 2012-2, p.422-430, In Chinese.
[12] Davis L, *Genetic Algorithms and Simulated Annealing*, San Mateo, California, USA: Morgan Kaufmann Publishers (1987)
[13] Holland J H, *Adaptation in Natural And Artificial Systems*, Ann Arbor: University of Michigan press (1975)
[14] Goldberg D E, *Genetic Algorithm in Search, Optimization And Machine Learning*, Addison-Wesley (1989).
[15] Xiao Chen, *The Application of DNA Genetic Algorithm Research*. Zhejiang University (2010), In Chinese.
[16] Xiaolan Xue, *The Application of Genetic Algorithm in the Flatness Error Evaluation* [J], the Journal Jinzhong College, 2009-06, 26th volume, 3rd, In Chinese.

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